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# EVALUATION OF THE PERFORMANCE CHARACTERISTICS OF CGLSS II AND U.S. NLDN USING GROUND-TRUTH DATA FROM LAUNCH COMPLEX 39B, KENNEDY SPACE CENTER, FLORIDA

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## ABSTRACT

**A new comprehensive lightning instrumentation system has been designed for Launch Complex 39B (LC39B) at the Kennedy Space Center, Florida. This new instrumentation system includes six synchronized high-speed video cameras, current sensors installed on the nine downconductors of the new lightning protection system (LPS) for LC39B; four dH/dt, 3-axis measurement stations; and five dE/dt stations composed of two antennas each. The LPS received 8 direct lightning strikes (a total of 19 strokes) from March 31 through December 31 2011. The measured peak currents and locations are compared to those reported by the CGLSS II and the NLDN. Results of comparison are presented and analyzed in this paper.**

## 1 INTRODUCTION

After over 40 years of deploying and using Lightning Instrumentation (Lightning Detection and Location Systems) at or around the vicinities of the Kennedy Space Center (KSC) much has been improved and gained; from monitoring the electric field during the Apollo days (mid-late 1960's) to the precise location of a lightning strike near and within LC39B with the deployment of the WX LPS lightning instrumentation (2011).

Both CGLSS and NLDN have been providing lightning detection and location data for the KSC with an expected margin of error (both detection and location) since these systems monitor big areas. Even though the margin of error has improved over the years, it is not possible for these systems to offer error free results.

The most recent NLDN performance characteristics has been evaluated using rocket triggered lightning data corresponding to 2004 through 2009 (Nag et al., 2011) where the resulting flash and stroke detection efficiencies were 92% and 76%, respectively; The median absolute location error was 308 m, and the largest error was 4.2 km.

The most recent comparison between CGLSS and NLDN was performed using historical data from 2005 and 2006 (Ward et al., 2008).

The WX LPS provides precise location and total detection of only a relatively small location at KSC (LC39B and its vicinities) but there is a possibility of implementing this system in multiple launch pads (like LC39A and CCAFS) which could all be interconnected and would provide 100% detection efficiency for all the launch pads within KSC and CCAFS.

## 2 KSC LIGHTNING LOCATION SYSTEMS DESCRIPTION

### 2.1 LC39B LPS, KSC

The LC39B LPS and its lightning instrumentation are described in detail in [1] and [2], respectively. This lightning instrumentation can be seen as an event-driven fast (up to 100MS/s) sampling DAQ system running 24/7 with sub-microsecond time accuracy which trigger signal comes from any of the thirty one (31) ground level sensors (9 downconductor currents, 12 dH/dt, 10 dE/dt), additionally a TTL signal from the LC39A lightning instrumentation system has been provided (mainly due to the use of LC39A for the Space Shuttle launches). After a qualified trigger is received, the signal of all the ground level sensors is recorded on a 30ms time window with 50% pre-trigger sampling at 100MS/s, additionally seven[1] high speed video cameras record up to 455 frames with 312.5us

[1] One additional high-speed video camera was temporarily installed (June 2011) about five kilometers southwest of LC39B. This camera is located in the firing room 1 of the Launch Control Center (LCC) and is currently pending final installation atop the Vehicle Assembly Building (VAB).

intervals (up to 142.1ms of video at 3,200fps) with a resolution of 1280x800, also with 50% pre-trigger.

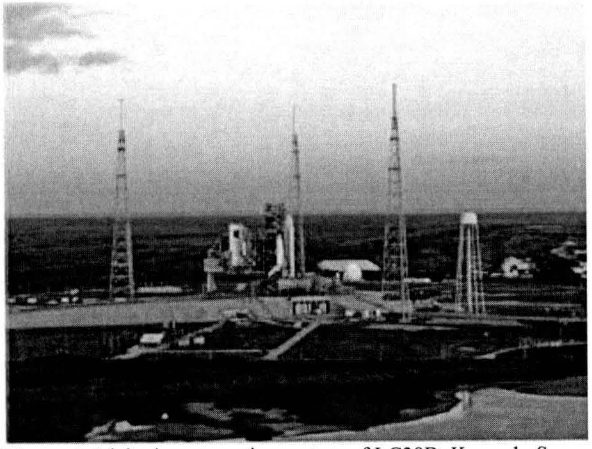

**Figure 1.** Lightning protection system of LC39B, Kennedy Space Center, Florida. Seen at the launch pad is the standby rescue Shuttle during the Hubble repair mission in 2009.

The LC39B LPS acquired data offers the capability of locating lightning strikes by means of:

- Time of Arrival (using dE/dt waveforms)
- Magnetic Direction Finder (using dH/dt waveforms)
- Visual inspection (using video camera records)

Additionally, downconductor waveforms offer a mean to corroborate between a direct and nearby lightning strike by its characteristic behavior.

## 2.2 CGLSS II, 45th Weather Squadron

"KSC has made major contributions to the development of two complementary systems for detecting and locating lightning, the Cloud-to-Ground Lightning Surveillance System (or CGLSS) and the Lightning Detection and Ranging (or LDAR) system. The CGLSS utilizes a network of gated, broadband electric and magnetic field sensors (Krider and Noggle, 1975) to detect the waveform signatures that are characteristic of return strokes, the high-current components of CG flashes (Krider et al, 1976; Herrman et al., 1976). When a proper signature is detected (in the time-domain) at two or more known locations (the antenna sites), the coincident times-of-arrival and magnetic directions can be used to compute the points where return strokes strike the ground (Krider et al., 1980; Cummins et al., 1998; 2006).

According to a time-domain antenna theory developed by M. A. Uman and his collaborators shortly after the Apollo 12 incident (see for example Uman et al., 1975), the initial peak of the electromagnetic pulse that is radiated by a return stroke is proportional the peak current in the stroke, multiplied by the speed of the stroke up the leader channel, and divided by the distance to the stroke. [Note: this theory is sometimes called the simple 'Transmission-Line Model' or TLM because it assumes the current pulse propagates up a straight channel, without distortion, and at a constant speed.] Since the CGLSS measures the peak field and can compute the stroke location, and since the stroke velocities are known and roughly constant, the CGLSS can also provide an estimate of the peak current in the stroke and its polarity." [5].

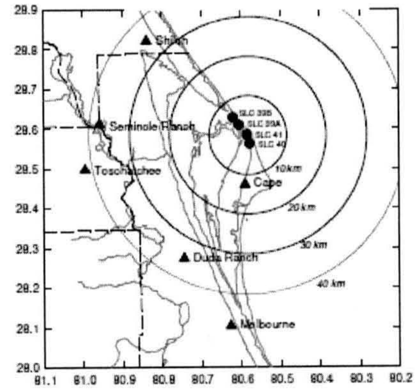


**Figure 2.** Map showing the location of 6 CGLSS II sensors (pending updated version)

"1995-1998, the system was converted to a 6-station, short-baseline network of medium-gain IMPACT (IMproved Accuracy from Combined Technology) sensors (Cummins et al., 1998)."

## 2.3 U.S. NLDN

The U.S. National Lightning Detection Network (NLDN) has been providing real-time, continental-scale lightning information since 1989 and it has undergone several improvements and updates. It consists of a nationwide network of "Improved Accuracy from Combined Technology" (IMPACT) sensors which basically use a combination of the Magnetic Direction Finder and Time of Arrival techniques [6] and is capable of producing the following estimated parameters: latitude, longitude, microsecond time, peak current, polarity, Cloud/Cloud-to-Ground indication and multiplicity for lightning strikes.

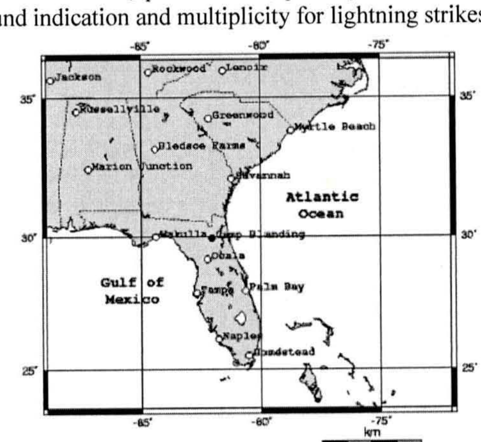


**Figure 3.** Map showing the locations of 15 U.S. National Lightning Detection Network (NLDN) sensors in aaround the Florida region (pending updated version)

As of the last reported nationwide hardware update, the NLDN currently has 114 IMPACT-Enhanced Sensitivity and Performance (IMPACT-ESP) sensors and based on the last published performance characteristic evaluation results

[7] it has a flash and stroke detection efficiencies of 92% and 76%, respectively, with a median absolute location error of 308m (the largest error of 4.2km) and the peak current estimation errors never exceeded 129%. It is worth noting the validation test referenced was done at the International Center for Lightning Research and Testing (ICLRT), at Camp Blanding, Florida, using rocket-triggered lightning techniques where intentionally the strike location is know but the acquired return strokes are only representative of regular subsequent strokes in natural lightning, consequently, the given performance characteristics a) are representative of the portion of the NLDN covering the Florida region (whose performance characteristics are not expected to be superior to those of the other parts of the network) and b) the flash detection efficiency is expected to be an underestimate of the true value for natural negative lightning flashes (since first strokes typically have larger peak currents than subsequent ones).

## 3 DATA

During the year 2011, from late March until December, the LPS was subject to a total of 48 lightning flashes (8 direct and 40 nearby) with a total of 89 return strokes (19 direct and 70 nearby) recorded on 16 different days.

This work will use only direct strikes to the LC39B LPS, all of which were negative flashes.

CGLSS II and NLDN data was provided for each day the LC39B LPS was directly stroke by lightning. Data consists of a text file providing: date, time stamp (UTC) with millisecond accuracy, decimal coordinates (latitude and longitude) with six significant figures, peak current (positive or negative) number of sensors, cloud or ground discharge (only for NLDN) and ellipse parameters.

The following CGLSS II and NLDN performance characteristics were determined: 1) stroke detection efficiency, 2) location errors, and 3) differences in peak currents estimates. Both systems, CGLSS II and NLDN, were compared against LC39B LPS data.

Each direct return stroke was correlated using GPS (Global Positioning System) time stamps to determine stroke detection efficiencies.

Geographical coordinates were used to calculate location errors. Only 4 strokes did not attach to the towers' air strike terminal, so downconductor current waveforms and video records were used to estimate their strike location. LC39B LPS towers' coordinates correspond to the center of each tower.

LC39B LPS peak current values are calculated from the algebraic sum of all (9) downconductors. From acquired data it is seen that the faster the return stroke is then more oscillations will be present in this algebraic sum due to the length of the downleads of the downconductors which are about 250 meters each.

Out of 5 multi-stroke direct flashes, ranging from a minimum of 2 and a maximum of 8 return strokes, only one flash had all return strokes (3) attaching to the same termination point with both, CGLSS II and NLDN, detecting 2 return strokes (the first and the third). It is believed the second return stroke was not detected due to the threshold of these systems. For the remaining 4 multi-stroke direct flashes the subsequent return strokes did not attach to the same strike location of the first return stroke.

There were two strokes attaching at two different locations simultaneously, both these strokes were reported by NLDN (one as cloud and one as ground discharge) but CGLSS II failed to report both of them. In both cases the attachment points were: 1) the air strike terminal atop the insulator of Tower 2 (about 181 meter height above ground level) and 2) ground level east and outside the LC39B perimeter about 550m and 620m (east and south-east, respectively) from Tower 2. Tower 2 is the east-most tower of the LC39B LPS and its closest distance to the coast line is about 650m (north-east direction). For the extent of this work, location calculations of these return strokes were made using the direct strike location to the LPS.

There was one 2-return stroke flash where the first RS stroke the LPS and the second RS was a nearby strike, both CGLSS II and NLDN detected both strokes but only the first RS is included in this work, additionally there was one 3-return stroke flash where the first RS stroke the LPS (tower 3), the second RS had two simultaneous attachment points (tower 2 and nearby, south-east of LC39B) and the third RS was a nearby strike (striking the same nearby location as the second RS). CGLSS II reported only the first RS and NLDN reported all three RS, the third RS of this flash is not included in this work.

## 4 RESULTS

### 4.1 Stroke Detection Efficiencies

Table 1 shows the CGLSS II and NLDN stroke detection efficiencies for 2011 were 19 return strokes attached directly to the LC39B LPS. For NLDN, the total stroke detection efficiency is 84% (16 of 19) which is better than the 76% reported by *Nag et al., 2011,* taken as an underestimate since rocket triggered lightning data (for 2004-2009) was used. The stroke detection efficiency for return strokes identified as impacting ground is 74% (14 of 19) which is about the same as the underestimate given by *Nag et al., 2011.* NLDN additionally exceeds at detecting all the first return strokes if these are not categorized as ground or cloud discharges, if so then the first return stroke detection efficiency is 75% (6 of 8). For CGLSS II the detection efficiency is 63% (12 of 19), maintaining this number for the detection efficiency of first return strokes and improving to 64% (7 of 11) for subsequent return strokes.

For more specific cases NLDN outperformed CGLSS II significantly with 100% (3 of 3) detection efficiency for single-stroke flashes compared to 33% (1 of 3) and again 100% (2 of 2) detection efficiency for strokes with multiple simultaneous attachment points (direct and nearby) but only 50% (1 of 2) once ground/cloud categories were taken into account compared to 0% (0 of 3) for CGLSS II.

Figure 4.1.1 shows the distribution of the detected strokes (CGLSS II, NLDN and LC39B LPS) by the LC39B LPS

current rise time. Rise times were between 1 and 7 microseconds.

**Table 1.** Summary of LC39B LPS Direct Strikes (March-December, 2011) with CGLSSII and NLDN Detection Efficiencies (DE).

| Direct Return Strokes (March-December, 2011) | No. of Strokes | No. of NLDN Detected Strokes | NLDN Stroke DE | No. of NLDN Ground Strokes | NLDN Ground Stroke DE | No. of CGLSS II Detected Strokes | CGLSS II Stroke DE |
|---|---|---|---|---|---|---|---|
| Total | 19 | 16 | 84% | 14 | 74% | 12 | 63% |
| First | 8 | 8 | 100% | 6 | 75% | 5 | 63% |
| Subsequent | 11 | 8 | 73% | 8 | 73% | 7 | 64% |
| Single-Stroke Flash | 3 | 3 | 100% | 1 | 33% | 1 | 33% |
| Multiple simultaneous attachment points | 2 | 2 | 100% | 1 | 50% | 0 | 0% |

### 4.2 Location Accuracy

Figure 4.2.1 shows a spatial distribution of locations for all the direct strokes detected by CGLSS (12) and NLDN (16). The origin (marked X at the center of Figure 4.2.1) correspond to the center of each tower of the LC39B LPS since each tower was directly stroke by lightning at least once during 2011. These locations are known from site surveys, additionally for 1 case (CGLSS II) and 3 cases (NLDN) the attachment point was along the downleads of the downconductors. For the purpose of this work, geographical coordinates of these locations were obtained after reviewing the downconductors current waveforms, and half the distance from the tower to the downcondutor grounding point was selected as the attachment point.

Figure 4.2.2 shows the histogram of NLDN and GCLSS II absolute stroke location errors for the 16 and 12 strokes shown in Figure 4.2.1. CGLSS outperforms NLDN regarding location errors with minimum, median and maximum location errors of 51, 155 and 467 m (for CGLSS II) compared to 133, 555 and 1,714 m (for NLDN) which in turn can be compared to 23, 308 and 4,239 given by *Nag et al., 2011*.

Figure 4.2.3 shows the absolute location error with respect to the number of reporting sensors. The range of reporting sensors was 2-5 for CGLSS II and 2 – 15 for NLDN with the largest absolute location error given when 15 sensors where used as part of the solution for the NLDN. It is not obvious that the location error tends to decrease as the number of reporting sensors increases, for both CGLSS II and NLDN.

### 4.3 Peak Current Estimates

Figure 4.3.1 shows the perceptual peak current difference between both systems, CGLSS II and NLDN, and the LC39B LPS, both systems underestimate the peak current between 20-40% even though it is important to point out that the LC39B LPS measured peak current is the combination of multiple (9) currents. There are two events where NLDN measured more current that the LC39B LPS and these correspond to 2 return strokes with multiple simultaneous attachment points (CGLSS did not detect any of these strokes).

Figure 4.3.2 shows a histogram with all the LC39B LPS peak currents and identify the range of peak currents for which CGLSS and NLDN detected strokes. The largest recorded current saturated the LC39B LPS at 174.3 kA and, excluding this event, the average LC39B LPS peak current was about 30 kA.

Figure 4.3.3 shows a relation between LC39B LPS and the number of reporting sensors for each system, CGLSS and NLDN.

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